FIRST SEMIANNUAL REPORT

PHYSICAL PROCESSES IN AN MPD ARC

NASA GRANT NGR-05-009-030

November 29, 1966

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This report summarizes progress on NASA Grant NGR-05-009-030 during the first semiannual period beginning in March, 1966.

As of this reporting date, construction of the accelerator and the associated vacuum facility is completed. The accelerator has been operated with argon propellant, and an initial survey of its impedance characteristics has been made. Results of these tests will be summarized later in this report. We will first outline the general engineering features of the device itself, in terms of problems arising from our project criteria, and the solutions to them.

Accelerator Design

The purpose of this program is to determine, as far as possible, the interior physical characteristics of an MPD arc which is itself representative of the arcs being investigated for possible thrustor application. Probes are to be our main diagnostic tool, at least initially, and thus, if these probes are to survive in the $\sim$ 100 kw arc environment, the current flow must be held to short pulses. Short pulse operation also has the advantage that given a sufficiently large vacuum tank, the background pressure will not have a chance to rise significantly even if the pumping system is slow; thus, conditions more representative of a space environment can be maintained.

A caution which must be exercised when employing pulsed operation, however, is that a true steady state must be achieved during the pulse in order that the observed arc behavior may be taken as representative of D.C. devices. Voltage, current, gas flow, and field distributions must hold steady during a major part of the "on time."

We have selected 500 microseconds as a pulse length which is probably much longer than any typical MHD or electrodynamic time constants of the system, yet far shorter than the time it should take to harm a probe. During this time, moreover, there should be no returning pressure wave from the far end of our 8-foot tank, so a good vacuum should be maintained.

A half-millisecond is, however, far too short a time in which to heat the typical solid tungsten cathode to thermionic emission temperatures. For this reason, we have incorporated into our design concept a "flash-heated" cathode of thin tungsten sheet, which is brought to emission temperature in a fraction of a second just prior to the discharge.

In order that the interior of the discharge region might be mapped with acceptable resolution with realizable probes, it was decided to make the overall scale size of this device considerably larger than what might be called typical of MPD arcs. The geometrical configuration is also much simpler than usual. It was recognized that this departure carries with it some hazard of producing atypical arc operation, also; however, the design selected can be easily modified by simple electrode inserts in order to approximate existing arcs, and so the design was not regarded as too much of a gamble. (The ultimate justification for the design has been, however, that quite representative MPD arc operation has been achieved, as will be described later.)

The final novel design requirement generated by our pulse mode is one for a fast-opening gas flow system which will establish a very uniform flow suitable for the arc in a time substantially shorter than two sonic transit times of the vacuum tank.

System Details

We will describe the various components of the system in some detail, here, with the aid of the photographs which constitute figures 1 through 6.

Figure 1 shows the accelerator structure, overall. The cylindrical anode is a stainless tube, 3.75 in. inside diameter, fitted tightly inside an alumina cylinder of 4.25" outside diameter which is cantilevered upon a nylon plate on the hinged cover plate of the vacuum tank. A narrow flange at the outer end of the anode supports a vacuum seal. The bias field coil, potted inside a slotted aluminum housing, rests near the end of the support insulator.

In Figure 2, the cathode and insulator can be seen. The cathode is a 1 cm wide band of 0.005" tungsten bent into a "hairpin," and clamped to the two halves of a split stainless steel support rod. The insulator performs the functions of: a) supporting the cathode structure and insulating it from the anode; b) providing a vacuum barrier between the discharge region and the atmospheric pressure region behind it; c) housing the gas supply system.

Figure 3 shows the insulator and gas supply system in full scale. The insulator is machined from "Mikroy," a type of ceramic made from a finely divided and compacted glass and mica mixture. Beneath the stainless plate which is cemented to its rear surface, there is an annular chamber of about 1 cm square cross section which feeds a set of twelve conical nozzles in the front face. Gas is dumped into the annular chamber from a small ($\sim 1\ cm^3$) high-pressure plenum by a very fast magnetic core valve. The valve, pulsed by a 20 volt, 10,000 microfarad electrolytic capacitor and

SCR switch, achieves full opening in less than 200 microseconds. (Preliminary gas flow measurements will be discussed later.)

The cathode assembly is shown in Figure 4. The two halves of the main supply conductor are cemented to a thin fiberglass separator, and potted inside an alumina sleeve. This structure achieves a vacuum seal against a step in the bore of the Mikroy insulator by means of the o-ring at the end of the alumina sleeve. It extends rearward beyond the main tank wall to a point where the main conductors from the cathode heating supply and discharge pulse supply bolt to the split rod.

This external connection area at the rear of the accelerator is seen in Fig. 5. The rectangular box on the table beneath the large flange contains a transformer which supplies the cathode heating pulse. With the cathode cold at the beginning of the pulse, approximately 200 amperes are drawn from the 220 volt primary line for two or three cycles; as heating progresses, however, the load resistance increases, and at the end of 0.3 to 0.4 seconds, the total load power, now balanced entirely by thermal radiation, is about 3 kw. A welding-type SCR control circuit switches this primary power.

The aluminum straps which bring up the cathode heating power continue upward past the accelerator connection and are attached to one end of the secondary winding of the pulse transformer which rests on the top frame. Each of the two straps is actually bolted at this point to the anode of a large silicon rectifier; these two rectifiers have their cathodes tied together and to the transformer secondary. In this way, both sides of the cathode strap receive the main pulse current identically, since in this circuit, the two rectifiers are in parallel. Yet, as far as the A.C. heating pulse is concerned, the rectifiers are back-to-back, and so the two sides of the heating circuit are not shorted by their common connection to the pulse transformer.

The transformer itself has the function of matching the discharge impedance, which is in the 50 to 100 milli-ohm range, to the pulse forming network which serves as the energy source. It is quite difficult, in terms of component values, layout inductance, and switching, to build a 0.05 ohm, 100 volt pulse line, where an impedance of 5 ohms, for example, is almost trivially easy; thus, the transformer.

The transformer is wound on an o-core of 2-mil lamination thickness, which weighs about 40 pounds. The windings are made up of sandwiched 6-in. wide strips of 10-mil aluminum. The primary has 50 turns of two thicknesses each, and the secondary has 7 turns of 12 thicknesses. As can be seen in Fig. 5, the 12-layer secondary conductor is brought directly out from the transformer and bolted to the anode flange at the rear of the accelerator.

The 5-ohm pulse line has six sections, each with $C = 8\ \mu\text{fd}$, and $L = 200\ \mu\text{h}$, and can be charged to 4 kilovolts if necessary. An ignitron serves as the switch.

Energy for the bias field coil is supplied by a 200 microfarad bank which can be charged to 1 kilovolt. At present, the maximum field attainable is 2400 gauss.

Figure 6 is a general view of the entire installation. The vacuum tank is of 1/4" stainless steel, and is 4' i.d. and approximately 8' between the ends at the axis. The pumping system consists of a 140 cfm Stokes forepump and a 16" NRC oil diffusion pump with a liquid nitrogen chevron cold trap.

The relay racks contain vacuum controls (right bay) and power, control, and delay circuits for the accelerator are in the center bay. The pulse line and bias energy banks are also contained in these bays.

Operating Sequence

Several functions, all transient in nature, must be carefully synchronized for proper operation of the accelerator. The actual sequence is the following:

1) The system firing switch activates the cathode heating pulser. A square switching pulse, variable in width between 0.1 and 0.5 seconds, is generated in this circuit, and is used in two ways. First, the pulse itself turns on the SCR which feeds 220 volt A.C. to the heater transformer; secondly, the drop to zero at the end of the pulse is differentiated to produce a timing fiducial which initiates all other events. Thus, the main system is fired at the instant the cathode heater is turned off. This works for the reason that the thermal decay time of the cathode ($\sim$ 0.5 second) is far longer than the entire time taken by the remaining events ($< 10^{-2}$ s.), and so, the cathode is still effectively hot for the discharge, while possible modulation of system characteristics by the presence of high A.C. currents in the ribbon during the shot is avoided.

2) The gas valve is opened.

3) After a delay of 1 to 10 milliseconds, (depending upon the propellant) the field coil pulse is switched on.

4) Exactly 2 milliseconds after the field coil is turned on (the field risetime), the main pulse line is fired.

Preliminary Measurements

The system has been put into initial operation with the use of argon as a propellant. The principal unknown among the accelerator parameters is the actual pressure and flow velocity of argon supplied to the arc. We are preparing to do this carefully through the use of a sensitive microphone-type gauge; for now, however, we have only the relative pressure measurements from a Marshall fast ion gauge which at least show that for a period of several milliseconds, beginning at from 1 to 5 milliseconds after the valve command, there appears to be a very steady neutral flow through the barrel.

Aside from this, we have made initial surveys of the arc impedance as a function of bias field and discharge current, as well as a measurement of the self-field (B_θ) of the arc at a few points in the interelectrode space.

We will present here only a brief summary of our initial observations. These data are preliminary in the extreme; their main value so far has been to show us that the device which has been constructed can indeed be called an MPD arc.

Our observations are the following:

1) For a bias field of 1000 gauss, the arc voltage drop is about 65 volts. Because of some leakage inductance in the transformer, the rise of the current to its steady value takes about 100 microseconds, and the decay, beginning 400 microseconds later, also takes a bit over 100 microseconds. Yet, the <u>voltage</u> of the arc jumps to 65 volts almost immediately at the beginning of the current rise, and maintains this level throughout the pulse to nearly the end of the current decay. We are unable

to detect any significant dependence of voltage upon current in the current range of less than 50 amperes to more than 2000 amperes.

2) Arc voltage depends upon bias field, increasing with increasing field. Within a very restricted range (between 1000 gauss and 2000 gauss) the drop is something like linear with B_Z.

3) In the 1000 gauss bias - 1000 ampere area of discharge operation, there is evidence for a rotating azimuthally asymmetrical discharge. A single B_θ probe (carefully nulled against B_Z pickup) displayed a fairly strong and pure 60 kc modulation superimposed upon its otherwise steady output, which corresponded to the 1000 ampere discharge current. The probe was halfway between the electrodes and behind the cathode. A pair of B_θ probes placed 180° apart in azimuth showed a 180° phase shift in their 60 kc components, a result which strongly indicates a rotation of the discharge at this rate. (Had we selected any displacement angle <u>other</u> than 180°, the sense of the rotation could also have been obtained; as it is, this data will have to be obtained later.)

The strength of this modulation appears to decrease with increasing B_Z, and its frequency also decreases. Indeed, the mean rotation velocity, if we take E_r = 30 v/cm, and a radius of 3 cm, appears to be just E_r/B_Z. One should probably look for some "resonance" between this speed and the Alfven "critical speed" of the propellant involved, but we have not done this.

Present Activity

The construction of the hydraulically operated probe carriage is proceeding at present. It allows continuous mapping over a 6 x 6 inch area in two dimensions without resetting of the probe. With its completion in about a week, detailed probing can begin.

As mentioned earlier, a sensitive capacitor microphone pressure gauge is under construction. With it, we hope to be able to determine the density and velocity of the neutral flow into the arc.

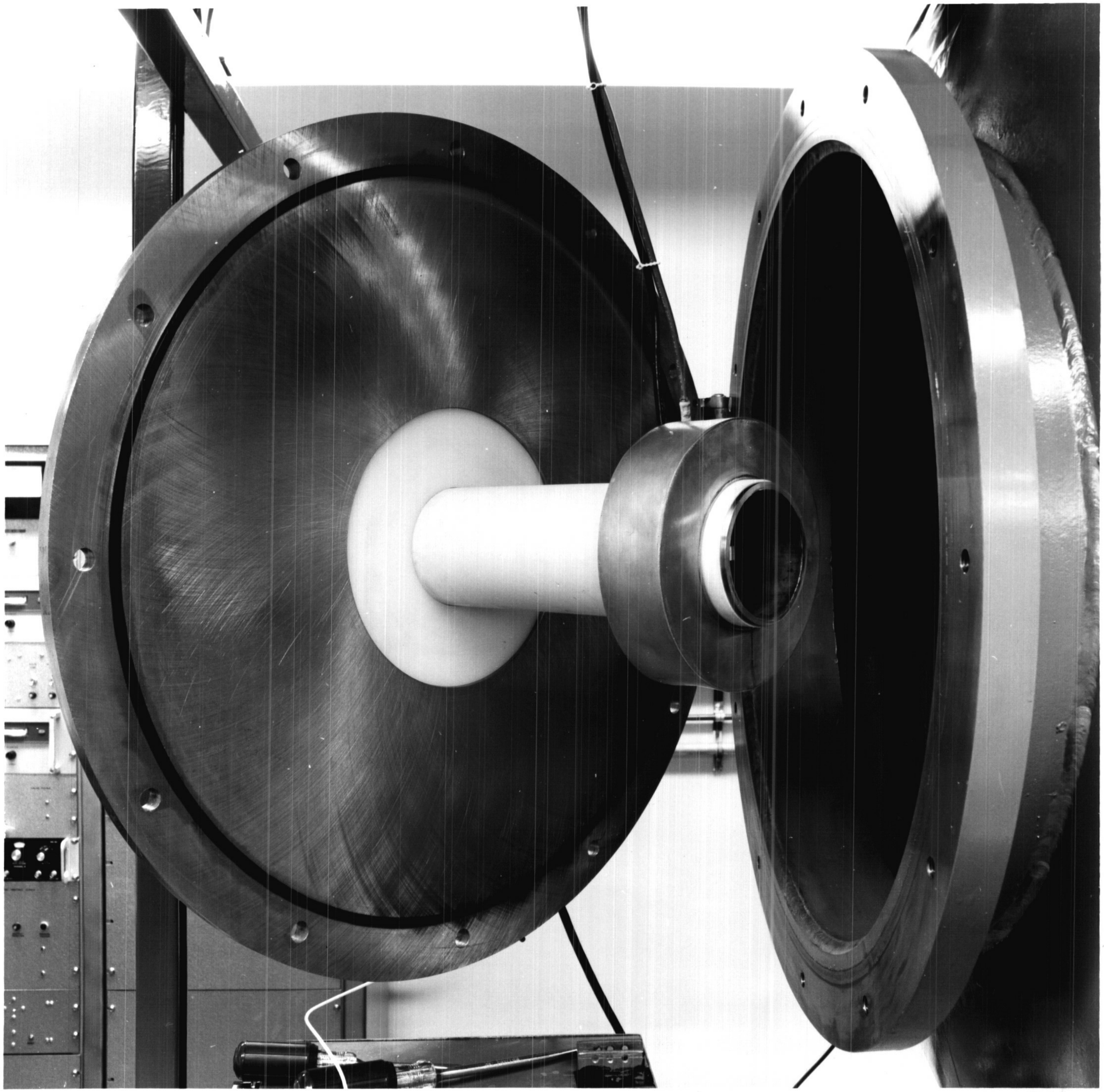

Figure 1

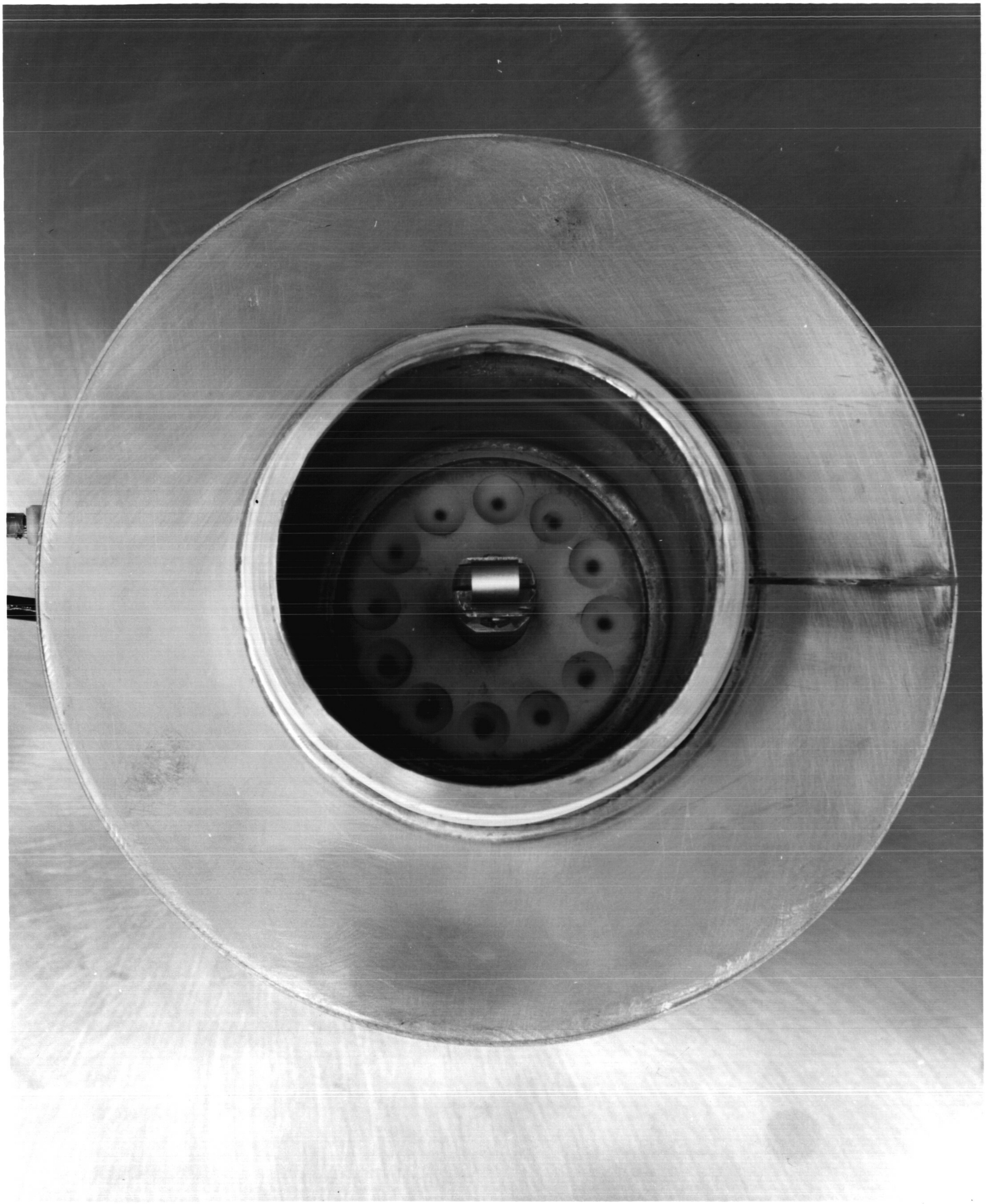

Figure 2

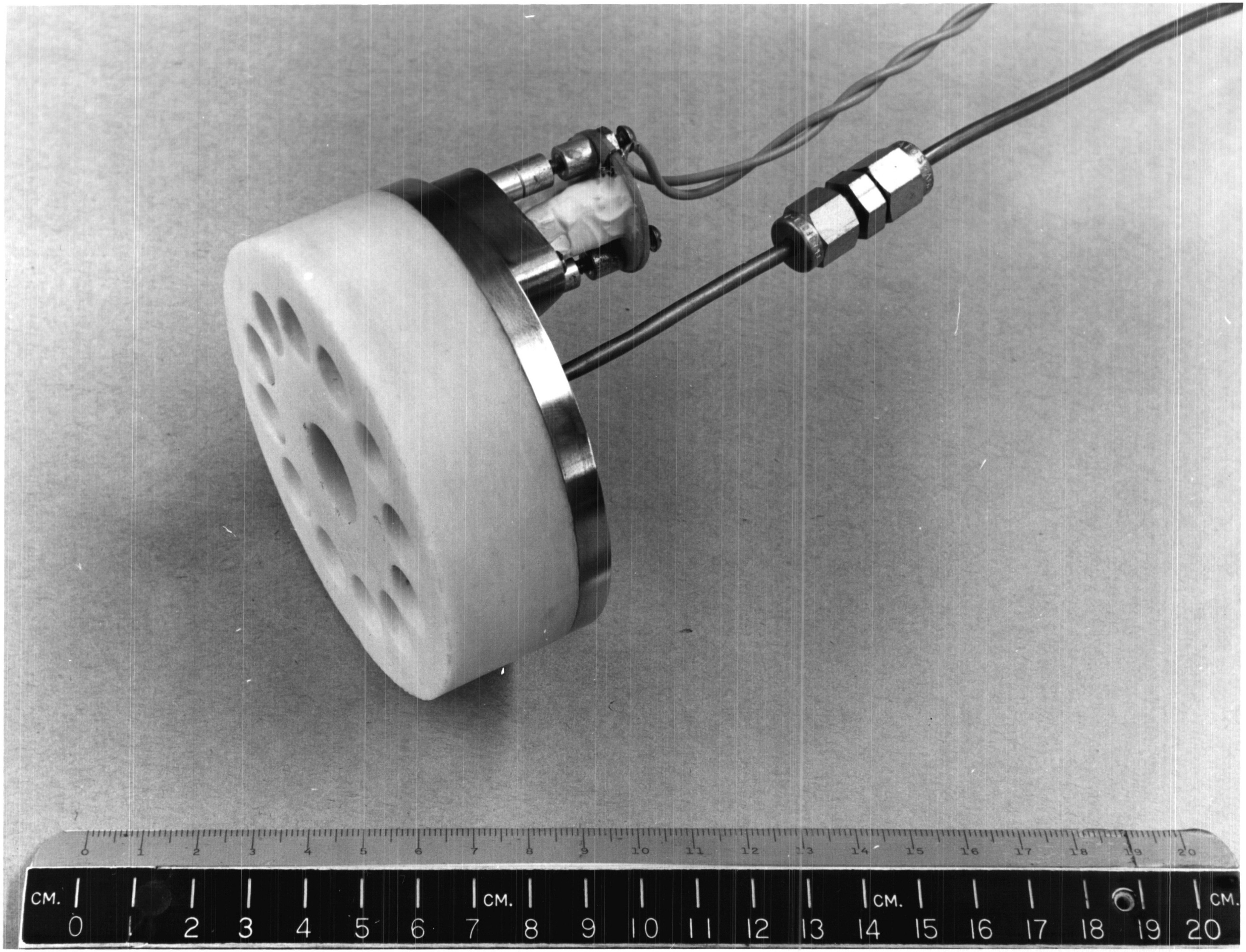

Figure 3

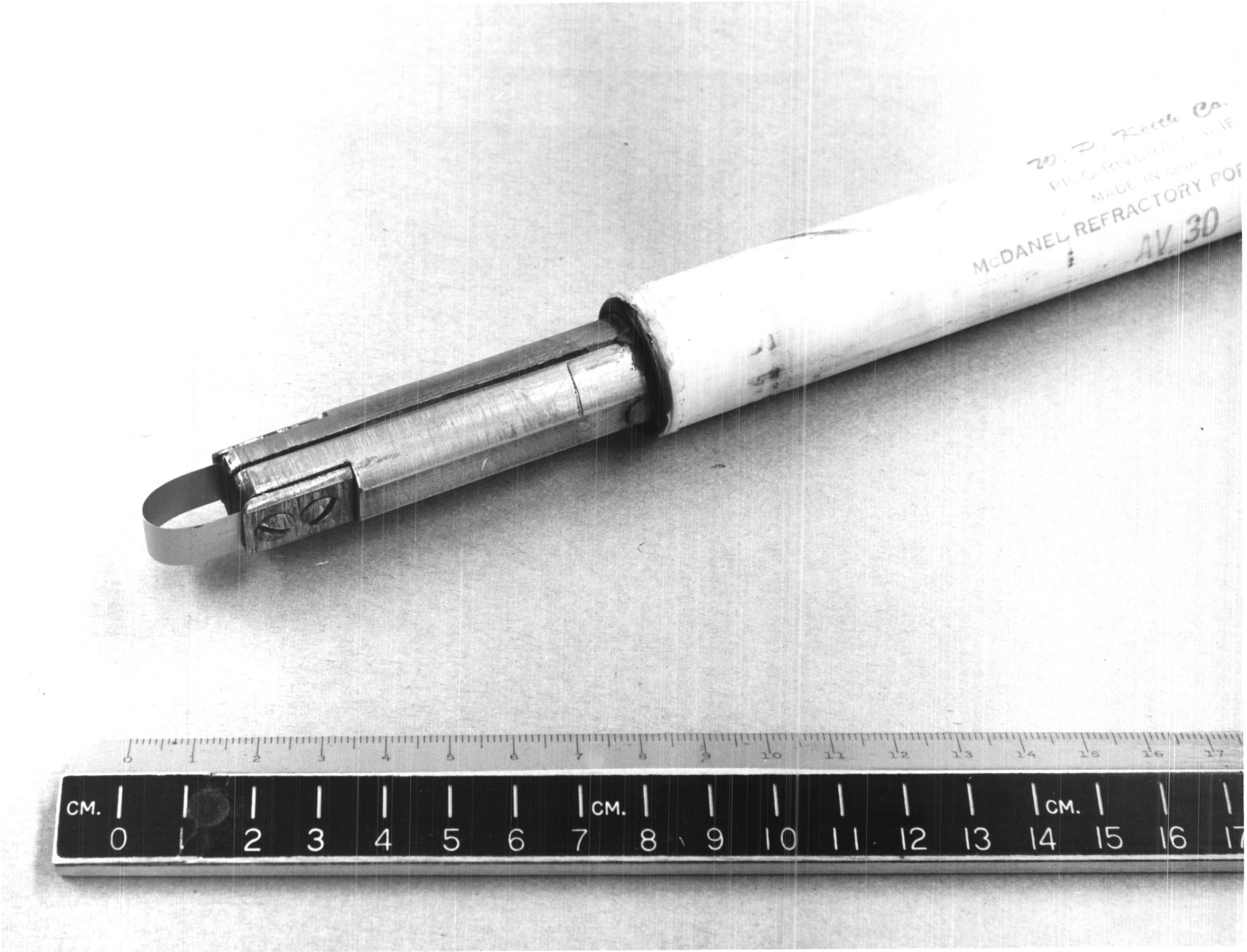

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Figure 4

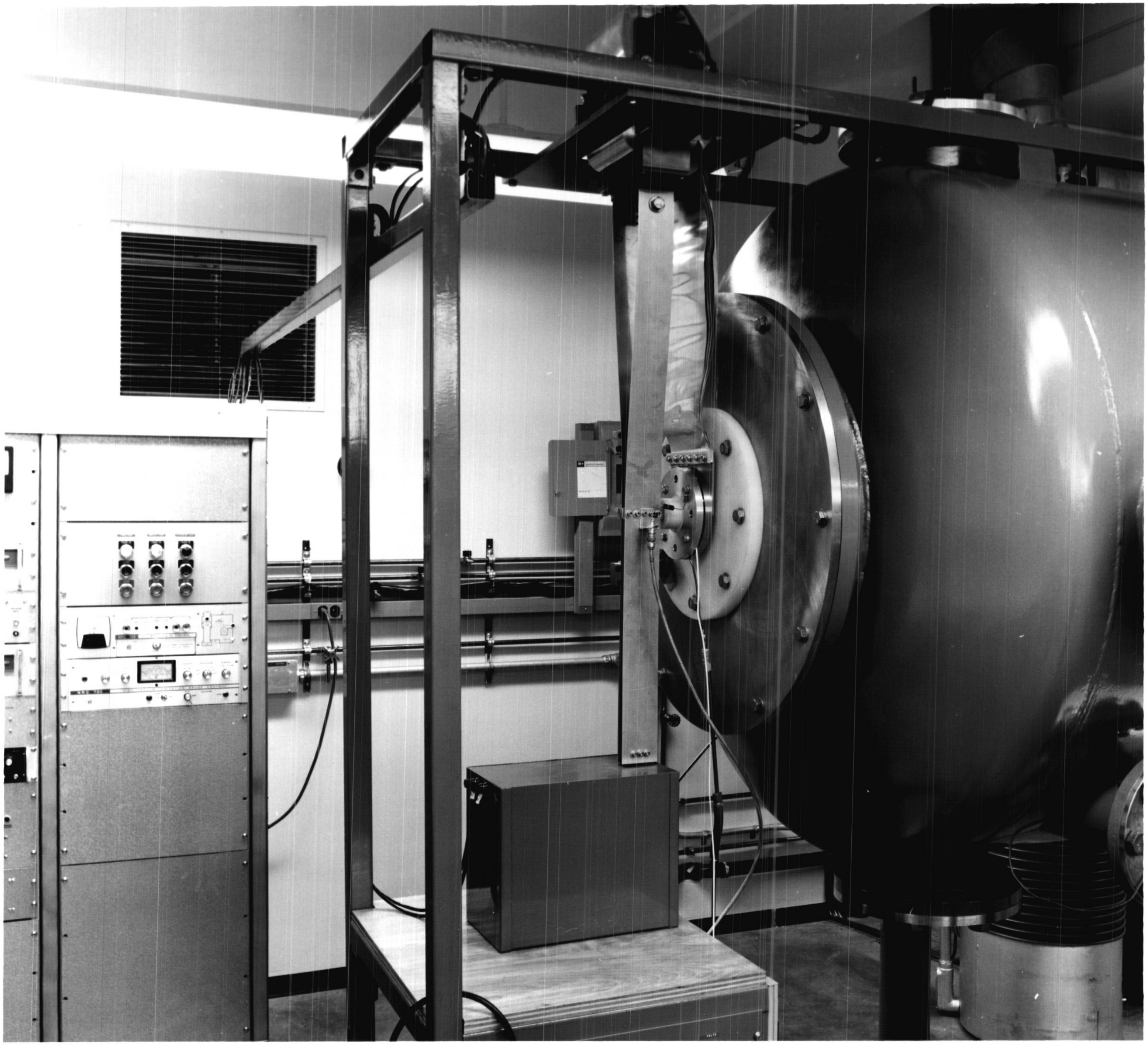

Figure 5

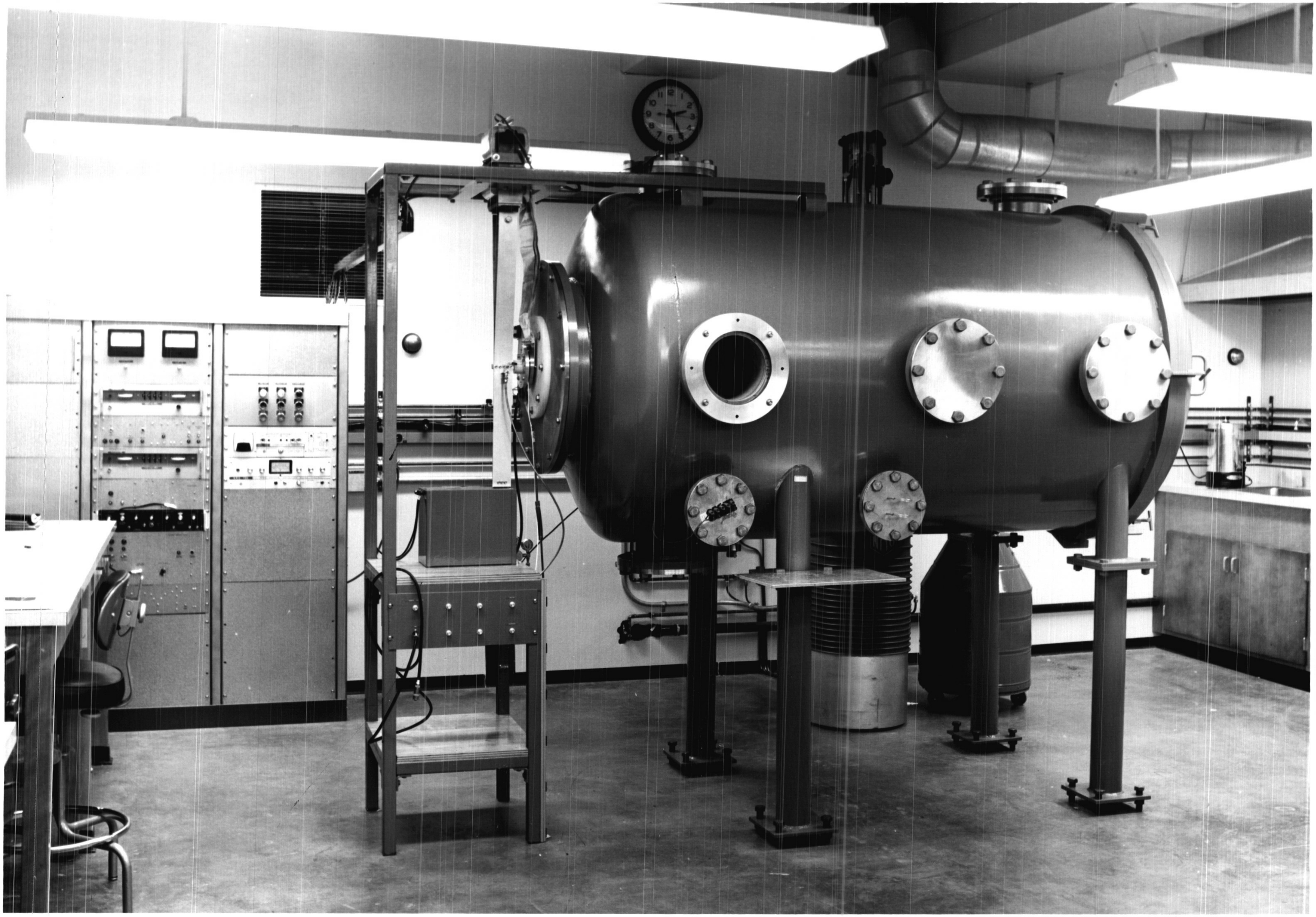

Figure 6